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A Mosaic Disease of Clover

A MOSAIC DISEASE OF CLOVER

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Aaron Raymond Kienholz

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INTRODUCTION.

The group of diseases whose cause is thought to be the abnormal functioning of some physiological process in the plant has come to be known as "physiological diseases," a convenient, but loosely used term covering diseases of a varying appearance and baffling nature. This very interesting group of diseases has been investigated for over half a century by botanists and tho many facts have accumulated, the primary cause of most of them is as obscure as ever. One of the most interesting and longest, most intensively studied of these diseases is that known as mosaic disease. This discase, together with other diseases causing the so called "degeneration" of potatoes has been given an increasing amount of attention within the last few years. Not only has the mosaic disease of potatoes been the subject of recent study but mosaic diseases generally have become increasingly important economically because of their recent severity on known hosts and their sudden destructive rise on new hosts of cultural importance. For an example of the latter we have but to point to the greatly increased severity of mosaic on potatoes in Maine and to the recent appearance and present severity of the mosaic of cucumber, sweet potato and sugar cane. When we consider that losses from potato mosaic for entire states are as high as 12 and 15 per cent while many fields average 25-75 per cent loss or even total loss in very limited areas we realize the importance of this disease if confined only to this one crop. Besides affecting Irish potatoes, mosaic is almost equally destructive on beans, tho not nearly so wide spread. It results in serious decreases in yield in limited areas on sugar cane, cucumbers, tobacco, tomatoes and sweet potatoes.

All investigation of any mosaic disease, whether on an economic or noneconomic host, whether destructive or not, leads to the accumulation of additional facts on, "that awful mosaic combination," as Dr. L. R. Jones calles it, and helps to estimate losses from it, devise control methods for it, and may even give some clue as to its primary cause. With this in view a disease found on red clover, Trifolium pratense L., similar in appearance to the mosaic on tomatoes and other plants has been investigated in a preliminary way. The present work brings together some of the more recent work done on mosaic, especially that of economic plants, the first appearance and subsequent course of those mosaic diseases which have appeared recently, together with control methods directed against them. Beyond very brief references to previous work as a background, this paper does not attempt to trace the historical development of mosaic diseases. To obtain this development together with very full discussions of the mosaic disease of tomato, tobacco and potato, reference is made to the work of Melchers (I), Allard (II) and Freiberg(III) and the full bibliography appended to each.

HISTORICAL SUMMARY OF MOSAIC DISEASES.

The longest and best known mosaic disease is that of tobacco. Next in order of length of time studied are the mosaic diseases of solanaceous plants generally.. This is due to the early recognition of the infectious nature of the mosaic of tobacco, the prominence of the mosaic symptoms in the solanaceous plants, their resemblance to the mosaic symptoms on tobacco and the family relationship of these solanaceous plants to tobacco with the resulting attempts at cross-inoculating them with the virus of tobacco mosaic. Within very recent years the mosaic diseases of other plants have come prominently to the front and together with them the increased importance of mosaic of such solanaceous plants as potatoes and tomatoes.

Melchers (III) says the disease on tobacco was first referred to by Sweeten in 1857 but was not thoroughly studied until 1885 by Adolf Mayer who called it "mosaic disease" in his publication the following year. Since that time many investigators in many lands have increased our knowledge of tobacco mosaic. Through all their work we notice a confusion of ideas and an inconsistency of results which show that more than one disease was under consideration and this uncertainty we have to deal with through out the earlier history of every mosaic dsease. Thus, Selby of Ohio reported a mosaic on cucumber in 1902 and Stone of Massachusetts in 1909, but neither secured evidence of its communicability, which has since been established,, and Gilbert (22) thinks their disease was due to malnutrition.

The mosaic of tomato was reported by Sturgis in 1899 from a field nipped by frost and later by Woods, who secured it thru severe

pruning. That this was a truly infectious mosaic is doubtful. However Clinton in 1908 described a mosaic disease of tomato and discussed its ability to infect other tomato plants, thus establishing the disease which he studied as a true mosaic. Woods by artificial inoculation secured the mosaic disease on potato in 1902 altho Orton in 1913 was the first to report potato mosaic as being present both in Germany, where he studied it in 1911-12, and also in Maine. Since that time it has become very prevalent and very destructive. Iwanowski (1903) reported a mosaic disease on kidney beans and Clinton (1910) found it on both lima and string beans. Sweet potato mosaic was found by Ensign and Rosen (52) in 1918 near Pine Bluff, Arkansas, while the destructive sugar cane mosaic was first noticed in Porto Rico in 1916.(11).

PLANTS AFFECTED WITH MOSAIC.

The expressed sap from any part of a mosaic diseased tobacco plant when injected into another tobacco plant will cause it to become diseased also. This occurs after an incubation period of usually 10-12 days, tho this may vary somewhat. Clinton in 1908 proved definitely that the mosaic disease of tomato is identical with that of tobacco. This he did by injecting the sap from a diseased plant of Nicotiana Tabacum into tomatoes and securing a very severe form of the disease. Pepper (Capsicum cerasiforme) and Jimson weed (Datura Stramonium) are also susceptible to the virus of tobacco mosaic, while potato (Solanum tuberosum) belladonna (Atropa belladonna) pokeweed (Phytolacca decandra) egg plant (Solanum melongena) and Datura fastuosa (Golden Queen variety) were among the solanaceous plants which resisted infection. Quanjer (43) however, makes the statement,"Tobacco mosaic is identical with or at least closely related to potato mosaic". He speaks of grafting tops of mosaic potato plants on healthy tobacco and tops of mosaic tobacco on healthy potato but adds, "Spreading from tobacco to potato or vice versa has not yet been observed by the author- - -." He obtained an interchange between tomato and some varieties of potato but not others. He adds, "It would seem that the contagium of tobacco has more difficulty in adapting itself to potato than to other Solanaceae and a wide field opens here for experiments on adaptation." Neither has the mosaic of tobacco proved to be intercommunicable with the destructive mosaic disease of beans.

Allard in 1915 (III) produced the interesting evidence that Nicotiana viscosum is subject to a mosaic disease which differs in

many respects from that of Nicotiana Tabacum in that it infects Datura fastuosa (Golden Queen variety) and does not infect tomato, a behavior the exact reverse of that exhibited by Nicotiana Tabacum. It differs in several other ways from the disease of Nicotiana Tabacum while in still others it is identical. In contrast to this, European workers have gotten practically no infections from tobacco on other solanaceous plants, a phenomenon for which no reason is known. Nishimura (38) lists the following plants as being susceptible to the sap from mosaic diseased tobacco plants: tomatoes (various varieties), Petunia violacea, Physalis sp., Datura Stramonium and D. Tatula, Hyoscyamus niger, Solanum nigrum and S. carolinense and varieties of Capsicum. He himself reports two new hosts, namely; Solanum aculeatissimum (Apple of Sodom) and Physalis Alkekengi. Similar to this is the fact that potatoes may not show any signs of the disease whatever, yet when their tubers are planted the following year they produce plants some of which show the disease. Potatotubers from a field which seems to be wholly free from mosaic may produce some diseased plants the following year. This is due to tuber infections, which cannot be detected. It isstill an open question whether potatoes show the disease on their foliage the first year or the second year after their infection.

A case similar to the above has been investigated by Nishimura (38) in which he found Alkekengi or bladder cherry (Physalis Alkekengi) to act as a carrier of the disease without itself showing the symptoms. The Alkekengi was inoculated, both from mosaic diseased plants of tobacco and Solanum aculeatissimum, and it remained normal in appearance thruout. When the sap from this inoculated plant was again injected into tobacco, typical symptoms of mosaic were produc-

ed. The virus suffered no diminution in its ability to produce the disease by passage thru an apparently immune plant nor was the length of incubation or the symptoms changed. This is merely an extreme case of what occurs in the inoculation of an older plant of Phytolacca decandra. Here the leaves already mature when the inoculation was made, do not show mosaic symptoms, while those not yet mature and all new growth formed after the inoculation, show the symptoms in varying degrees of intensity.

One may be led to inquire, is there no chance for recovery from the mosaic disease? This is a mooted question. Early workers, as Woods and Beyerinck, have described cases of apparent recovery in the case of certain colors used in an attempt to note the effect of different colored lights on the mosaic disease of tobacco. Chapman (13) however found these cases of apparent recovery not to be true recovery at all. Altho outward, visible appearances were practically normal, yet the juice of the plant, still retained its infective power. Allard makes the statement, "In no instance has there been a case of actual recovery from true mosaic" Clinton in (1914) cites a case in which the juice from a healthy appearing leaf at the base of a plant, "calicoed" or mosaic diseased above, failed to infect. The only case which the writer has been able to find, of a case of recovery from mosaic disease is that recorded by Brierly (11) in which he transplanted several severly mosaic diseased tomatoes into his laboratory. One died, the other withered, was cut back and sent up three new shoots which were normal in appearance. The symptoms of the old plants were typical of mosaic and a concoction made from its dried leaves gave infection, so it must have been mosaic diseased. But the sap from the new shoots was

wholly free from infectious properties, and mosaic symptoms, hence a case of recovery, three healthy shoots growing from a diseased stock. The question arises, are these new shoots growing from the "calicoed" stock immune to the"virus" of the disease, i.e., have they acquired immunity as the result of one attack? The author did not prove this point and one can but wonder at the probable outcome of a very interesting case.

The recently discovered destructive mosaic of sugar cane has several hosts besides sugar cane. Brandes (11) reports them as follows: sorghum, crab grass, foxtail and Panicum have been proven conclusively to be susceptible, while with corn, rice and millet no experimental proof is available, but field observations point to their being susceptible also. Other hosts will undoubtedly be found as experimentation progresses. The mosaic disease of cucumber, which Gilbert (22) says has perhaps been present in the Middle West for the last fifteen years but which has come into prominence only within the last five, has lately been reported by Jagger (29) as present on many other hosts of the family Cucurbitaceae. Among them he mentions, pumpkin, squash, gourd, muskmelon, citron, watermelon and other lesser known members of this family. Wild cucumber (Echinocystis lobata) is also susceptible to the same disease and is a factor in its distribution as we shall see later. The families Campanulaceae, Lobeliaceae, and Compositae, together with Cucurbitaceae make up the order Campanulales. Jagger inoculated members from all of these families with sap from mosaic diseased cucumber plants and obtained a mottling of the leaves in one species of Lobeliaceae (Lobelia erinus var. gracilis) and one species of Compositae (Helianthus debilis). He obtained

no infection in the species of Campanulaceae experimented with. Those which became mottled produced the mosaic desease when re-inoculated on cucumber proving the mottling to be a true infectious mosaic disease. Most of the members of the family Cucurbitaceae were susceptible to cucumber mosaic in varying degrees but there were two species among those tried which could not be infected, tho repeated inoculations were made. These were Ecballium elaterium and Citrullus vulgaris (red seeded citron). Jagger (II) also reports a second kind of mosaic which appears at Rochester, N. Y. in which only the leaves are mottled and no "white pickle" effects were produced on the fruits. It has been transmitted, by rubbing, to the summer crookneck squash and the muskmelon.

The mosaic disease of beans is found chiefly on pea beans (Phaseolus vulgaris) tho it is likewise found on snap and dry beans. McClintock(II) found it stunting and mottling the leaves of the Sieva type of pole and bush varieties of lima beans but not any of the other varieties. The sweet potato mosaic was found on the Nancy Hall variety but as it is not infectious it should not be called a true mosaic. So far no investigations have been published on its affecting other varieties of sweet potatoes. A mulberry disease, very similar to our mosaic diseases has been found in Japan by Suzuki (III). The peanut mosaic which McClintock (II) mentions is not an infectious trouble and his report is the only one available. The sweet pea is affected rather seriously by a mosaic disease which was first studied by Taubenhaus (II) in 1912 after which his published report appeared. All varieties are affected with the exception of the dwarf Cupid varieties which seem to be immune.

A mosaic is described as being produced artificially on violets

by Woods in 1902. No further note of this disease has come to the writers attention. Onion mosaic has been found locally in West Virginia (42) on the Multiplier variety and it has done a moderate amount of damage in one county.. Raspberry mosaic has been reported as severe on certain forms in the lower Hudson valley (42), while mosaic on peony in Ohio and celery in Massachusetts have been reported (42). Whether these mosaic diseases on onion, raspberry, peony and celery are infectious or merely chlorotic conditions has not been reported. Spinach is subject to an infectious mosaic-like disease which is however,known as"spinach blight". It has been known for many years and as early as 1907 was causing serious losses to truck growers in Virginia. Its cause was first thot to be malnutrition but McClintock and Smith(32) have shown it to be a disease of the type of tobacco mosaic, transmissable by means of insects and thru needle pricks. Experiments show the Savoy type of spinach to be more resistant than other varieties.

Thruout this list of plants known to be susceptible to mosaic we see a certain specificity of the virus. That is the virus of one disease may infect only the one species of plant or it may infect only certain species and not others. Thus we see the cucumber mosaic which confines itself chiefly to the family Cucurbitaceae yet within that family are two species which it does not infect. On the other hand it can infect plants wholly outside its own family. Likewise the mosaic disease of Nicotiana Tabacum can infect tomato readily and potato not at all, while the mosaic of Nicotiana viscosum cannot infect either tomato or potato. The disease follows lines of relationship rather closely yet there are gaps in this line and sudden jumps to plants not related, which

makes the investigation rather confusing and the results impossible of accurate prediction. This leads us to the matter of varietal susceptibility which is of such intense interest in all branches of pathology and of such vital importance in all considerations of control. Taking up only those crops upon which the disease has been thoroly studied and in which differences occur upon differnt varieties we turn first to the potato.

By far the most susceptible variety is Bliss Triumph of which the Plant Disease Bulletin (42) says, "Bliss Triumph has come to be regarded as inseparable from the disease and occurs in practically every field where this variety is planted. Indeed most growers are so accustomed to seeing mosaic diseased plants of this variety that they would be apt to fail to recognize a healthy plant if it could be shown them." This makes the Bermuda seed potato problem a particularly important one because the Bermuda growers seek an early market for their potatoes. This market demands a red potato and they are compelled to grow the Bliss Triumph which is so very susceptible. Green Mountain ranks next in susceptibility and is rapidly becoming affected, fields of this variety free from the disease being difficult to find. The Report (48) lists the susceptible varieties as follows:

Bliss Triumph
Green Mountain
Green Mountain Group
    Lincoln
    Mills Pride
    White Lady
    Carmen No. 1

Chile red (from Maine)

American Giant

Hamilton's Early

Early Ohio.

The following varieties are listed as, "rarely or not at all affected."

Irish Cobbler

Early Rose

Rural Group

Davis Warrior

Other resistant varieties are Peerless and Spaulding Rose.

Johnson (30) reports Irish Cobbler susceptible to mosaic injury in Virginia;and curly dwarf, which Quanjer (43) says is a more severe form of mosaic, is said to be prevalent on Irish Cobbler in Iowa. Evidently a great deal of work covering different parts of the country, under different climatic conditions is needed to clarify many of these doubtful points.

Reddick and Stewart(45,46)believing that the use of resistant varieties is the best way of controlling the mosaic disease of beans,have gone about their work in a thoro manner, testing all the varieties of beans with a view to finding resistant or immune varieties and then using them as the basis for hybridizing and selecting to secure a good yielding, immune or highly resistant variety. Plants of many varieties were grown in pots and a susceptible variety was used to test the strength of the inoculum. These varieties were then inoculated by rubbing their fully expanded juvenile leaves on the underside until they were slightly injured with several, rolled and slightly crushed, diseased leaves.

The two papers referred to above give a full list of the susceptible and resistant varities which it is not necessary to repeat here. The White Marrow (a field or shell bean) showed a supressed case of the disease and was judged to be immune or highly resistant. The bastard bean, a broad, flat-podded, flat-seeded, late type of marrow bean, proved to be very susceptible. The pea beans, which are most cultivated in New York, proved to be very susceptible, as high as 50 percent showing symptoms and occasionally causing total failure of the crop. The Robust, a variety from Michigan, has remained immune to mosaic for several years, it is a good yielder but is susceptible to anthracnose. It is hoped to overcome this weakness by crossing with a White Marrow which is immune to anthracnose. Later work has shown the Robust variety the only one immune under field conditions, tho others have shown varying degrees of resistance.

The Wisconsin station in 1911 made the statement that the cherry and peach types of tomato are naturally resistant to mosaic and that by crossing either of them with the variety Earliana a good yielding, desireable strain resistant to mosaic would be obtained. Allard (II) however found no variety of tomato resistant to the mosaic of tobacco. The peach and cherry types having finer foliage than the others may show symptoms of a very attenuated character, which, he says, may have led to the conclusion that certain varieties are more or less immune or resistant to the disease.

Brandes (11) states that, "More than a thousand varieties of cane have been determined to be susceptible to the mosaic disease." Many of these are commercially grown varieties, practically all the varieties grown for the mills being susceptible. Due to the

length of time mosaic has been present in Java the growers thru unconscious selection have obtained resistant, tho not immune, varieties. The varietal susceptibility varies from the immune Japanese varieties, thru the resistant Java varieties down to the white Otaheite or Bourbon cane which is very susceptible often being so badly affected as to be worthless for milling. Different varieties show a rather constant percentage of susceptible individuals, thus one variety will show 60 percent mosaic in each of several rows grown under essentially the same conditions, while another variety may show 100 percent infection in each row. This suggests an individual resistance within a variety, which can be made use of in selection and breeding. Some varieties of the North India or Japanese type of cane such as Kavangire and Cayana 10 have remained immune for the several years they have been under observation even tho surrounded by severely infected canes. Some broad leaved varieties grown in the variety test plots at Audubon Park, New Orleans, appear to be immune also.

DISTRIBUTION AND PREVALENCE.

Mosaic diseases of various kinds are found generally distributed thruout the region where their host plants grow. Melchers (III) says of tobacco mosaic,"- - this malady seems to be present thruout the tobacco growing regions of the world, altho there are some countries growing tobacco extensively from which no reports of its occurrence have been seen." In the United States, it is present where ever tobacco is grown. In New England, it has been known for some time, tho it has never been as serious as in other states. In Massachusetts it is present thruout the state, varying in severity with the seasons and with the cultural methods employed. Chapman (13) says however, that it is a more serious disease in the tropics and in certain parts of Europe than in this country. Reinking (51) reports from the Philippines; "The true mosaic has not been observed but an unimportant chlorotic condition is frequently noted." While Carpenter (12) reports it as being present in the Hawaiian Islands.

The mosaic of sugar cane is noted by Brandes (11) as prevalent in Java, Hawaiian Islands, Egypt, Cuba, Porto Rico, Argentina and the United States. In the United States the presence of this mosaic disease was first noticed in July, 1919. A survey was immediately made of the Gulf States and its distribution was found to be rather general. It was found to be present in Louisiana, Florida, Georgia, Alabama and Mississippi, as outlined on the accompanying map. (fig. 1.). The largest and also the most severely infected area is in Louisiana, many fields being 75 per-cent infected. Florida has several scattered infections and as cane there is grown chiefly for syrup the patches are not large.

The infections are all small, local ones confined in most cases to the one field in which the diseased cane, shipped in from other states, was planted. In Georgia the few infections are all located near Cairo in the southwestern corner of the state. In both Alabama and Mississippi the mosaic has been found at but one place from which it has spread very little. The survey of Texas was still underway when the bulletin (11) was issued so no results from that state are available.

Regarding the distribution of potato mosaic the Bulletin (42) says; "The range of mosaic appears to be limited only by the presence or absence of susceptible varieties." Bliss Triumph and Green Mountain being especially susceptible, the Bulletin states; "It therefore appears that a map of the United States representing the range of the Bliss Truimph and potatoes of the Green Mountain group would also show in general the range of mosaic." The accompanying map, (fig. 2), drawn from data given in Table I taken from the Bulletin (42) shows the distribution and prevalence of this disease of potato. In 1913, immediately after Orton's report of its destructiveness in Germany and its presence in Maine, a search was made for it thruout the United States, but no trace was found of it in Minnesota, Wisconsin, Colorado or other western states. In 1918 however it was reported from the northern tier of states extending from the New England States to Washington and Oregon. It is severe in the southeastern states and the disease also exists in Indiana, Illinois, Virginia, West Virginia and Idaho. "It is probable that it will occur in all parts of the country where affected seed is planted," quoting from the Bulletin. It exists in Bermuda where much of our early potato crop comes from,

in Canada, especially Ontario and the Maritime Provinces, and it is also quite generally distributed thruout the potato growing regions of Europe.

Melchers (34) mentions the first appearence of the mosaic, "white pickle," "wart disease" or "nubbins" of cucumber in Kansas and records it as present also in Wisconsin, Michigan, Ohio, New York, Louisiana, Pennsylvania, Minnesota, Iowa, Illinois and Ontario, Canada. The Bulletin (42) reports it also from Connecticut New Jersey, South Carolina, Georgia, Mississippi, Texas, Indiana, Vermont, Rhode Island, Kansas, Colorado and California. It is most severe in the Middle West where pickles are grown for the factory. "Mosaic seems to be increasing from year to year, both in its range and destructiveness. In Wisconsin it is at the present time the limiting factor in the pickle industry," the Bulletin (42) states and adds further that total losses have resulted from it in Michigan, while Massachusetts and Pennsylvania report losses of from 10-75 percent.

Bean mosaic was reported asshown in Table I and its distribution and prevalence is indicated in the map, (fig. 3) based on data taken from the Bulletin (42). It was reported for the first time in 1918 from Massachusetts, Connecticut,New Jersey, Pennsylvania, Tennessee,South Carolina, Georgia, Florida, Louisiana, Texas,Wisconsin and Idaho. Reddick and Stewart (45) give its range as, generally distributed thruout the bean growing section of the United States. In New York it follows the pea bean growing sections and is not severe in the yellow eye and kidney bean sections. It was very serious in Oregon in 1918 and was also prevalent around Washington D. C. It is found in Ontario spread

generally from the Peninsula to Detroit.

Tomato mosaic was found in New York, New Jersey, Pennsylvania, Delaware, Georgia, Florida, Louisiana, Ohio, Illinois, Wisconsin, Minnesota, Missouri, Kansas, and Oregon, of these Georgia, Louisiana, Wisconsin, Missouri, Oregon and California being reported for the first time in 1918 in the Bulletin (42). It ranged in severity from practically negligible in most cases to severe in Kansas, while Oregon had a general,, severe attack worse than ever before.

Spinach blight besides being reported from Virginia for several years, has been found in Ohio and New York and it probably exists in all the spinach growing regions.

LOSSES DUE TO MOSAIC.

The losses due to mosaic are often considerable. This statement has been especially true the last two or three years. Because of the difficulty of estimating the reduction in yield due to a disease and because of the lack of standard methods for judging the percent of disease present in a field, the estimates of losses vary somewhat for the same region. This variation however is not a serious one and the reports of the Plant Disease Bulletin (42) are fairly accurate, especially for large areas. The losses, further, are usually recorded as the amount of reduction in yield or the percentage of loss in yield, and seldom in dollars and cents. Because of the varying market price money estimates are less accurate than percentage reduction in yield, tho money estimates bring the facts to us in a more startling form.

Murphy (36) is the author of the often quoted statement that there is a loss of 1⅓ bushels of marketable potatoes for every 1 percent of mosaic present. In Canada mosaic diseased potatoes gave a yield of 57.8 percent of normal. Of this crop only 82.7 percent were marketable while of healthy normal potatoes 91.6 percent were marketable. He says the trouble is constant every year and where present affects 20 percent of the crop giving a steady loss of 20 to 30 bushels per acre per year. He adds however, "The eating qualities of the (diseased) potatoes are not impaired." The disease has rapidly become more severe since 1916 until in some states, as Vermont, it is the most serious potato disease. On Long Island in 1917, fields of 15 to 30 acres were plowed up because of heavy infection by mosaic with a resulting loss to individual growers of two to three thousand dollars. In the South

also the disease is a serious problem entailing losses of 25 to 75 percent in some fields, the amount varying somewhat with the year. One commonly held opinion is that mosaic of potato reduces the yield ⅓ while leaf roll reduces it ⅔ but the Report (48) gives the common opinion of the plant pathologist present; "that mosaiced plants give, on the average, only about half the yield of healthy ones." The accompanying map (Fig. 2) and Table I show in detail the amount of potato mosaic present. The total loss thruout the United States is given as 11, 006,000 bushels which represents an enormous money loss, whatever market price the potatoes are selling at. Wortley, reports frequent losses of 20 to 50 percent in Bermuda from the effects of mosaic.

Bermuda gets most of its seed potatoes from Ontario and the Maritime Provinces of Canada. This trade was threatened by the prevalence of mosaic in Canada. The seed from these diseased fields when sent to Bermuda produced an increased amount of mosaic which caused considerable loss. The potato inspection service however has reduced the amount of mosaic in these Provinces very materially and Canada has retained the Bermuda seed trade.

The losses due to bean mosaic are given in Table I and Fig. 3 . The total loss for the entire United States being 433,000 bushels or 1.78 percent of the entire crop. In some sections bean mosaic is rivaling bacterial blight in importance and more serious than bean anthracnose in some regions. Losses from mosaic range from a trace in most states to 20 percent in Oregon. In Western New York where dry beans are grown commercially 15 to 20 percent of the plants are affected while 50 percent is the average infection where susceptible varieties form a large part of the crop.

Diseased beans, moreover, set few or no pods so the seriousness of the disease is apparent. Barss of Oregon reports 80 to 90 percent infection in some places but says diseased plants yield ⅓ as much as healthy ones. Ontario suffers somewhat from this disease also. In some parts of New York the growing of beans has been abandoned because of the prevalence of the mosaic disease and pathologists have been forced to work on it in the hope of controlling it.

Brandes(11) says little data on losses in the United States due to sugar cane mosaic are available but that some figures obtained in Louisiana make it probable the decrease in yield will be as great as in Porto Rico if the disease becomes widely spread. With 100 percent of the stalks infected we may expect a reduction in yield of 10 to 38 percent but as only 27 to 45 percent were reported as diseased the actual loss in tonnage varies from 4.5 to 12.16 percent. In Porto Rico where the disease has been noticed only since 1916 the disease has spread so rapidly that some areas have 75 to 100 percent infection and in these areas the output of sugar from 10 mills was reduced almost 40 percent. In the Hawaiian Islands, likewise, infection is nearly 100 percent and the yield of sugar, compared with healthy stalks, is reduced 5 to 40 percent.

Tomato mosaic does little damage in most areas tho in others it is a factor to be dealt with. Cucumber losses from mosaic vary from a trace to as high as 75 percent in Pennsylvania or lead to the abandonment of the crop in some regions. Squash are seriously affected locally in Texas while watermelons are affected somewhat in certain regions. Spinach blight is reported by

McClintock and Smith (32) as causing very serious damage locally in Virginia by reducing the yield materially, injuring the marketability of the product and causing losses thru allowing land on which spinach is grown as a winter crop, to lay idle. Some farmers have abandoned the crop while others grow it only on newly cleared land. Data collected for several years indicate the annual loss from spinach blight in eastern Virginia to be 20 percent of the crop or a money loss of $200,000 to $400,000 each year.

The loss due to tobacco mosaic is hard to estimate, Chapman (13) says, because of so many factors involved. If the disease is severe the loss is often great, as much as hundreds of dollars for one field. The diseased leaves are of a poorer quality and the buyer when seeing much mosaic in a field will not pay as much per pound. Thus we have two sources of loss which are difficult to estimate, but in years of severe attack the money loss is considerable.

SYMPTOMS.

Mosaic diseases are almost always recognizable, either by a mottling of the leaf color due to alternating dark and light areas or by a stunting and dwarfing of the plant with a crimping and crinkling of the leaf surface, or, if the disease is severe, by a combination of both of these classes of symptoms. The symptoms for all mosaic diseases are essentially uniform tho the details of mottling, dwarfing, leaf crinkling, etc. differ on different hosts.

The symptoms of tobacco mosaic are observable on the leaves of plants of any age, from seedlings to mature plants. The leaf is divided into dark and light areas which become more definite and more differentiated as the disease becomes more severe. The light areas are usually between the large vascular bundles tho they may occur indiscrimminately over the leaf surface. The dark areas become darker green which Chapman (13) says is due to the greater photosynthetic functioning which they must carry on. The light patches become lighter green changing to a yellowish or even a white. In some extreme cases the light colored areas become brown and dead. In mild cases there is no distortion of the leaf in shape or surface, but in more severe cases the leaf has a "savoyed" appearance due to the more rapid growth of the dark green areas, which raise up in blister like pouches. Sometimes the leaves are so distorted as to be little more than the midrib. The leaves likewise are thicker, more leathery, less elastic and make a poor grade of tobacco. Allard in 1912 (III) brot to our attention the mottling of the corolla of mosaic diseased plants which he says is a surer means of identifying mosaic. The corollas may be very much distorted and the capsules supressed and bearing no seed. In

the field diseased plants seldom produce double corollas but when these plants are transplanted to the green house and cut back extreme distortion of both leaf and flower occurs. Individual differences cause different expressions of the disease such as mottling or stunting. This, Allard (1) thinks, is due to individual differences and not to a difference in the degree of virulence of the virus. Likewise the difference in symptoms between different genera of the Solanaceae is due to their individual constitution.

The symptoms of tomato mosaic disease are similar to those of tobacco mosaic. They vary in severity with the varieties, broad leaved varieties being most severely infected. The mottling is noticeable also on the green fruits and on the stalks while on the ripe fruit, which ripens normally, the red color masks the mottling. The petals do not show mottling as they sometimes do in tobacco. In some cases the leaf tissue is very scanty, leaving little beside the narrow filiform midribs. This is given the name of "fern leaf." The symtoms appear quickly and more prominently in young, quick-growing plants (fig. 5) and almost disappear when the plant becomes older.

On potato also the symptoms of mosaic resemble those of tobacco mosaic. The mottling occurs on any part of the leaf, usually however the light areas occur between the veins of the leaf. The light areas vary in shape, size, color, distinctness of outline and frequency of occurrence. They may be merely crinkled, or distorted with the margin uneven. The mottling becomes less distinct with the age of the plant but the crinkled leaf still serves to identify it as mosaic diseased. Unless the disease is mild

the diseased plants are smaller than normal. In some districts, as in Colorado the symptoms are suppressed. Quanjer (43) says "curly dwarf" is a more intense form of mosaic and calls it a secondary form of mosaic. In it the plant is very much stunted and dwarfed, with the leaves resembling curly kale. The leaves likewise are dark green showing no yellow spots. This extreme form does not appear in shady sheltered places. The disease normally appears when the plants are four to seven weeks old or about eighteen inches high.

In petunia the leaves are much wrinkled with large dark green areas along the midrib. The blossoms may be affected in streaks or patches but never mottled as in tobacco. In pokeweed the symptoms resemble very closely those of tobacco.

Melchers (34) describes the symptoms of cucumber mosaic as being a characteristic wrinkled or "savoyed" appearance of the leaves together witha mottled effect. The disease however is peculiar in that it shows varying but definite symptoms on the fruits. In some cases part of the fruit may be mottled while the rest is yellowish white. The darker portions of the fruit grow more rapidly and push out as dark green lumps giving the name of "wart disease" to this appearance. In others the fruit may become pale yellow or almost white when only partly matured and remain in that condition, giving us the name of "white pickle" often applied to this disease. Others may be pale yellow or dark green and not mottled but small and distorted, from which fact the name of "nubbins" is derived. The vines are stunted, the leaves somewhat dwarfed and sickly and the whole yields poor bloom and inferior fruit. The symptoms on the other cucurbits are very similar, the pattern and degree of mottling varying somewhat, as does the degree of dwarfing.

In sugar cane mosaic, Brandes (11) describes the symptoms as a general pallor of the leaves, noticeable at a distance. The pallor is due to the lighter colored areas of the mottled leaves. These affected lighter areas are irregular, and in one type of disease have a washed out appearence with indefinite demarkation while in the other type they have a yellow color and are sharply defined. A great many patterns exist because of the variation in size, shape and amount of the light colored areas. These patterns are very constant and by them one can distinguish one variety from another. The symptoms become more severe with each following generation and result in a series of secondary symptoms, in which white opaque spots appear in the light colored areas and may occupy 20 to 30 percent of the leaf area. The canes may also become cankered with discolored water soaked patches on the internodes, which may crack, causing the cane to dry out. The whole plant becomes dwarfed and yellowed as if it had suffered from drouth.

Bean mosaic has symptoms similar to those of mosaic diseases generally. It is characterized by a mottling of the leaf, and when the disease is severe, a marginal wrinkling, the whole leaf cupping downward and the upper surface covered with blister-like bumps. The plant may also be considerably dwarfed. In spinach mosaic the plant becomes slightly yellowed and mottled, then takes on a savoyed or distorted appearance. The leaves finally become very badly distorted showing a mere feathery midrib, the older leaves brown and die, finally the whole plant dying. This entire progression takes place during the life of the one plant, differing in that respect from other kinds of mosaic in which the

symptoms remain fairly constant during the life of the one plant but which become much worse in the following generations. Sweet potato mosaic (52) manifests itself by a mosaic effect of the leaves, a wrinkling of the surface, a distortion of the leaves and a dwarfing of the vines. The sweet pea likewise shows a distinct mottling of the leaf and a dwarfing of the young growing shoot.

HISTOLOGY .

Very little information is to be obtained from the study of the histology of mosaic diseased leaves, and as a result, not much work has been done with histology in view. Chapman (13) has investigated the histology of all parts of mosaic diseased tobacco plants. The greatest differences between the light and dark areas are found in the most severely diseased leaves while in the mildly diseased leaves the structure approaches that of the normal leaf. Chapman agrees with Woods that the light colored areas are the diseased ones but places more emphasis on the somewhat abnormal or diseased condition of the dark green areas. In the yellow areas in badly diseased leaves, the palisade tissue is not developed at all but all the tissue is of a spongy parenchymatous nature, closely packed together. In mildly diseased leaves the palisade cells of the light colored areas become nearly as broard as long and their chloroplasts disintegrate or congregate in groups. Some authors find an absence of epidermis and a disintegration of cell walls but this must be a very advanced stage of the disease. The dark green areas are abnormal in that the palisade cells are narrower and more closely packed than those of normal leaves. Chapman also examined the stems and roots of healthy and mosaic diseased plants and found no differences what ever.

Melchers (111) found very little structural differentiation between the light and dark areas of mosaic diseased tomato leaves, or between healthy and diseased leaves. He did not find the palisade cells cuboidal or undeveloped as has been reported for tobacco mosaic. He found the light colored tissue to be slightly

thinner than the dark green tissue, especially in older leaves. The epidermis appeared normal and no difference in size or shape of the chloroplasts in healthy and diseased tissue could be noted.

In potato however, greater differences are discernable between the structure of the dark and light colored areas of mosaic diseased leaves and the healthy normal leaves. The light colored areas are much thinner than the dark areas at all ages of the leaf and the difference is often as great as 30 microns. This thinness is due to the shortening of the palisade cells in the light colored areas which become ½ to ⅓ the length of normal palisade cells and slightly wider taking on a cuboidal shape. In some cases the change from the cuboidal diseased palisade cells to the nearly normal palisade cells of the dark green areas is abrupt while in others it is very gradual. The spongy parenchyma seems normal except in the light cclored areas where the chloroplasts are a light greenish yellow.

MICROCHEMICAL STUDIES.

In order to ascerain what plant substances occur in plants which are mosaic diseased, we resort to microchemical and macrochemical methods. The first method has many weaknesses but an accumulation of results drawn from many samples give us facts which have a large degree of accuracy. Microchemical methods should be checked against macrochemical methods when ever possible, but it is difficult to get enough material of either light or dark areas from mosaic diseased leaves with which to make macrochemical tests.

Freiberg (II) has determined the relative abundance of various elements and substances in the healthy and diseased areas of mosaic diseased leaves. He finds that there is no unbalanced condition with regard to the inorganic elements essential to the plants. He found that nitrogen ammonia, iron, calcium, magnesium, potassium, phosphorus and sulphur were present in equal amounts in both healthy and diseased tissue. He found, however, a greater amount of protein present in the chlorotic areas than in the dark green areas while with carbohydrates he found, regardless of the time of day, a greater amount present in the darker areas than in the lighter areas. In only one instance, that of nitrogen, was he able to verify by macrochemical methods, the results he had obtained by microchemical means.

Schultz, Folsom, Hildebrand and Hawkins in their, "Investigations of the mosaic disease of the Irish potato," published in the Journal of Agricultural Research 17: 247-274, picked five sets of leaves from healthy and mosaic diseased potato plants, each set being under like conditions of weather and time

of day. They were dried and tested for sugar and starch with the following average results, expressed in per cent of dextrose on the basis of dry weight.

	Healthy plants	Diseased plants
Reducing sugar	1.94	2.84
Non reducing Sugar	4.26	4.38
Total Sugar	6.20	7.22
Percent of Starch	20.7	16.6

The above data would indicate the greater amount of total sugar and the lesser amount of starch in the diseased leaves than in the healthy ones. The authors add that their work is preliminary and their results based on too few determinations to draw any definite conclusions from.

The excellent work of True and others(60) on the constituents of normal and blighted spinach brings out some interesting facts, some of them opposed to the work indicated above. They found that there was less reducing sugar but much more sucrose present in the blighted tops than in the normal tops. This gave the blighted tops a sweetish taste when eaten in the uncooked condition. More than twice as much starch was found in the diseased tops as compared with normal tops. The starchs and sugars were present in about equal quantities in both normal and diseased roots. The total ash was essentially equal in both diseased and healthy plants. Proteins were found to be slightly less in the diseased tops than in the normal tops though the reverse of this was found in the roots.

INFECTION AND PHYSIOLOGICAL RELATIONS.

As early as 1886 Mayer found that tobacco mosaic was infectious and could be artificially transmitted from one plant to another. Since that time, many other mosaic diseases have been experimented with in the same fashion. As a result various methods of artificial infection have been developed. Cutting the stems or petioles and inserting diseased tissue is a favorite method. Sap expressed from diseased plants may be injected hypodermically into any part of the experimental plant or a drop may be placed on the leaf and several needle punctures made through it. The juice may also be sprayed on the leaf surface and the surface rubbed. Allard (1) has shown that high infection results from painting the expressed juice of a mosaic diseased tobacco plant on the leaves of healthy tobacco plants by means of a brush or soft rag. Spraying or dropping the virus on the uninjured leaf produced little infection. This is explained by the fact that infection takes place through the trichomes which are broken. This Allard proved by getting a fair degree of infection by alternately cutting the trichomes on diseased and healthy leaves. He likewise found the percent of infection to be much higher following inoculations made at many places on the plant compared with inoculations made at only one place.

Chapman (13) says the juice from all parts of a mosaic diseased tobacco plant is infectious though, "the percentage of infection obtained from the root extract is considerable lower than that obtained from the leaves." Allard (II) in 1915 showed the presence of the active virus in the capsules, filaments, anthers,

pistils and even ovules of mosaic diseased tobacco plants. Reddick and Stewart (45) secured their infections by rubbing several partly crushed diseased bean leaves on the underside of healthy leaves until the surface was slightly injured. Chapman (13) has shown that handling tobacco seedlings after dipping ones hands in juice from diseased plants gives about 60 percent infection. Doolittle (II) obtained infection by breaking off healthy leaves and applying the broken end of a mosaic diseased stem to the wound. Infection has also been secured when the juice from mosaic diseased potatoes was inoculated into potato tubers. By means of grafting diseased tops on healthy stocks or vice versa the disease is sometimes transmitted when no other method of infection is successful.

Hunger in 1903 proved the mosaic disease of tobacco to be highly infectious but not contagious. All of Chapman's (13) work verifies this statement though he did get two percent infection. He thinks however this is entirely due to accidental infection, for all that is necessary is to break the trichomes on the leaf to secure infection a thing which is easily done merely by leaf contact. Insects also must be rigidly excluded in order to make results accurate. Jagger (II) got four infections out of six plants when he grew healthy cucumber vines in contact with mosaic diseased ones. This must have been due to the breaking of the trichomes of the leaf through contact. He did not secure any infection however where mosaic diseased cucumber vines mingled their roots but not their foliage with healthy vines. Reddick and Stewart (47) grew healthy bean plants in contact with mosaic diseased ones and secured no infection. Quanjer (43) has definitely shown that potato mosaic

is not contagious and does not spread through contact of foliage alone.

Mosaic diseases are peculiar in that no method of infection seems to secure, consistently, a 100 percent infection while on the other hand the disease occurs spontaneously. The first result may be due to some weakness in technic due to ignorance of the causal agent. The second may be due to ignorance of the means of dissemination through soil, seed, or by insects. Some of this erratic appearance is explainable by insect transmission. Westerdijk (1910) however mentions tomato mosaic reoccurring periodically after the disease had once disappeared, tho new seed was used each season. Although Woods (1902) and Hunger (1905) said they were able to secure mosaic of tobacco at will by severely pruning or mechanical injury, Allard (III) in 1912 says, "The writer's experiments do not bear out the conclusions of earlier investigators that a true infectious mosaic can be produced in plants by simply cutting back."

Chapman (13) enclosed tobacco plants in bags of different colored cloth and found that this treatment affected the appearance of the disease greatly. With red light the mottled effect became less striking but the "causal agent was still highly infectious" and the mottling became more intense when the plants were again exposed to light for a time. Orange light intensified the mottling and the causal agent was as virulent as ever. In blue light the mottling was suppressed or completely absent, and the supression seemed more or less permanent, but the causal agent was as infectious as in any of the mosaic mottled plants hence no real cure was affected as Lodewijks had maintained. It has been noticed for

some time also that the mottling is less prominent in tobacco grown under shade than that grown out in the open. Freiberg (II) objects to too hasty an interpretation of the results obtained by Chapman and thinks them due to the relative amount of light absorbed by the different colored cloth hoods. Blue absorbing most, would act as a heavy shade and reduce the mottling effect. He stresses the effect of light on temperature and chemical reactions as making the whole problem a very complex, deep-seated one not to be solved by a few experiments.

A condition resembling true mosaic may be due to the lack of plant food in the soil, but it has often been shown that such a lack of plant food cannot bring about a true mosaic condition nor even intensify it as Chapman (13) has proven. He has given beds the regular amount of fertilizer used in tobacco culture and then has doubled or trebeled the amount of nitrogen, potash and phosphoric acid, in different beds, but no mosaic was produced in any case. Liming is said to lessen the prevalence of the disease but Chapman has not found this to coincide with his field observations nor his experimental results. He gave varying amounts of lime to different beds of both new and infested soil and found that no mosaic diseased seedlings recovered nor was there any difference in the amount of infection among the seedlings planted in the different beds of the second series, in which seedlings both diseased and healthy were planted. Brandes (11) likewise states that fertilizers merely give the whole plant a darker green color and stimulate its growth but do not lessen the amount of disease. He also says, "Liming the soil has no more effect on diseased plants

than the application of fertilizers."

The soil was formerly thought to have much to do with the causing of mosaic disease and Sturgis in 1898 said that tobacco mosaic was more abundant on close, clayey soils than on open, porous soils. Brandes (11) states that the sugar cane mosaic in Porto Rico was thought to be due to worn out soil, but the disease encroached on all types of soil including the most fertile. It is generally held that the soil has nothing to do with causing the disease and that it may lessen or intensify the symptoms only as it retards or hastens the growth of the plant.

Not much is known concerning the effect of climate on mosaic though it is a known fact that potato plants infected with mosaic when planted in, "certain warm districts," as Colorado and Iowa, do not develop characteristic symptoms but rather a kind of curly dwarf. The regular symptoms are developed through out the East from Maine to Florida, which makes the case of Colorado and Iowa all the more unexplainable. It is stated that high temperature is favorable to the disease, but no experiments have been tried to determine the correctness of the statement. Moisture, likewise, is said to favor the disease but here also no substantiating facts are obtainable. Freiberg's (II) work seems to indicate the possibility of recovery from mosaic through subjection to low temperature and the appearance of mosaic when the temperature is high and the light intensity relatively great.

MEANS OF DISSEMINATION AND TRANSMISSION.

To Allard belongs the credit for proving that the dissemination of mosaic disease of tobacco is by means of insects. In 1912 (I) he pointed out the correlation between outbreaks of mosaic disease and aphid infestation and that when plants are kept free from aphids they are usually free from mosaic. He transferred aphids feeding on diseased plants to healthy plants and secured infection. In 1914 he published this work in a more complete form. This means of dissemination was to be expected by analogy with bacterial and fungous diseases. Chapman transferred white flies from diseased to healthy tobacco plants but failed to get infection. Allard first found a large tobacco aphid to disseminate the disease. In 1917 (1) he recorded the spinach aphid and a large green aphid from lettuce as spreading the disease also. He later indicated the inability of red spiders to transmit the disease. In the above cases the plant lice were found to be inocuous unless they had previously fed on diseased plants. Brandes (11) states that field observations indicate an accompanying insect infestation with every mosaic disease outbreak. He says, "The cane leafhopper (Tettigonia sp.) in particular has been noticed to accompany the rapid spreading of the disease." Aphids were also present and caged plants did not become diseased while uncaged did. Melchers (34) says, "Insect control is imperative.," and cites the work of Doolittle (II) who got infection from melon aphids (Aphis gossypii, Glover) transferred from diseased to healthy cucumbers. Cross inoculations from diseased cucumber to muskmelon were made by means of these aphids. Later he (18) proved

that the mosaic disease of the wild cucumber appeared very early in the season and that the disease was disseminated from these centers of infection to the neighboring fields by means of striped cucumber bettles and other insects.

Schultz and his coworkers in the work cited on page 30 have indicated the relation of potato mosaic to insect transmission. Tubers from hills grown under insect-proof cages yielded a progeny only five percent of which showed mosaic. Aphids from mosaic diseased plants were transferred to healthy plants with a resulting mosaic count of fifty percent, but the progeny from all the plants exposed to aphids were one hundred percent diseased. Plants in alternate rows were infested with aphids and kept free from aphids by fumigation. The aphid-free row yielded 11 percent infection (from the tuber) while the aphid infested row gave 67 percent infection or 56 percent infection due to aphids. Several species were used. McClintock and Smith (32) have by extensive experiments shown that aphids transmit the blight of spinach and may retain the infective principle long after they have ceased to feed on diseased material and will even transmit it to their offspring which in turn are infectious to healthy spinach. This may be a method of the virus for bridging the gap between consecutive crops.

Quanjer (43) does not think the virus of potato mosaic lives saprophytically in the soil for any length of time but that it lives, if at all, in the tubers which remain in the soil and the following year send out no aerial branches but only tuber bearing stolons. moreover extensive experiments have been carried out by Allard (1) in which he allowed the roots of seedlings to grow

through a mass of infectious material in the soil and yet no infection resulted. He says infection depends on injury to the root and proves it by securing infection by mixing infectious material with soil so that roots torn in transplanting came in contact with it. If the roots have time to heal and then grow through a mass of buried mosaic diseased leaves they will not become infected. Insect injury on the roots may give the infective agent an entrance. When infection does occur in healthy plants growing in soil which formerly raised diseased plants the infection perhaps comes from injured roots coming in contact with the broken roots of former mosaic disease plants.

The work of all investigators point to the fact that tobacco mosaic is not inheritable. Allard (II) secured infection from the crushed ovules or seeds of mosaic diseased tobacco yet these seeds when grown produced healthy plants. He found that the progeny of those plants which resisted infection from many inoculations were no more resistant or immune to the disease than those which became readily infected from one inoculation. Thus there seems to be a barrier between the embryo and the placenta which the causal agent cannot pass. There is no such unanimity of opinion regarding tomato mosaic. Westerdijk (1910) says, "By the field experiments it has been shown without doubt that the disease is inheritable," for she secured a certain percent of mosaic seedlings from both healthy appearing and mottled fruit from a mosaic diseased tomato plant. Allard (II) however secured healthy plants from mosaic diseased tomatoes and all his results are opposed to those of Westerdijk, he states that they may be dealing with different diseases. If there is embryomic infection, he says, it is very rare. This in view of the fact that the infective prin-

ciple is present in both green and diseased fruits.

Potato mosaic is pseudo-hereditary in that it is transmitted through the tubers which show no visible signs of infection yet bear mosaic diseased plants. The Report (48) says, "The transmission of mosaic is recognized to take place through the seed tubers. In addition the tubers from apparently healthy plants frequently produce mosaic." Similarly sugar cane mosaic is transmitted through the seed-pieces giving rise to mottled shoots as soon as they appear, a condition known as "primary infection." This is of great importance in the spread of the disease by means of shipments of cane seed from one country to another and in matters of control. Stewart and Reddick (II) in reporting on bean mosaic state that, "The disease is transmitted through the seed.," and that bean seed from infected plants produce diseased seedlings. McClintock (II) reported regarding cucumber mosaic that, "These observations indicate that the disease is carried by the seed," and Doolittle and Gilbert (18) have shown that it is transmitted through the seed in the case of wild cucumber. The pokeweed does not transmit the disease through its seeds for one may see a diseased mother plant surrounded by a large number of small healthy seedlings. It, however, being a perennial, retains the disease in the large tap root and the new shoots growing from this are diseased. Spinach blight is not inheritable and plants grown from seed from diseased plants are perfectly healthy. There is no evidence that the disease is transmitted by adhering to the seed or by existing in the seed coats and then infecting the germinating seedling. The spreading of the disease by means of workmen and by cultivation is an important method in tobacco culture. Work-

men handle diseased and then healthy seedlings while they are transplanting and consequently spread the disease. Tools of cultivation are efficient instruments of dissemination. Workmen by topping, budding or worming spread the disease by contact and are a fertile source of disease dissemination.

Whether there is any permanent infestation of the soil as in some of our common soil diseases, in the case of mosaic disease of tobacco is not known. Allard (1) says tobacco mosaic will infect plants regardless of the type of soil or the previous crop conditions. There seems to be no direct relation between previous out-breaks of the disease and present infection, either in the seed or in the field. Steaming the soil does not prevent the appearance of diseased plants and he holds that infection must come from "sources external to the soil." Brandes (11) has found "no indication that the contagion persists in the soil after a crop has been removed." Healthy cuttings planted in soil in which diseased plants had previously been growing showed no signs of mosaic. Quanjer (43) thinks the causal agent must pass through the soil but that it cannot live there as a saprophyte from one crop to the next. Botjes (10) states, "In my own experiments, where one or two years intervened between the two crops, there never was any influence from a preceding diseased crop to be detected- - -." He however says that following mild winters, some disease may be detected in the crop immediately following the diseased one, tho this may be due to infection from living tubers remaining in the ground. Though there is no permanent soil infestation, yet the disease spreads through the soil as Botjes (10) has shown. In sandy soil rich in humus the disease may spread more than two meters. The

resulting infection becomes visible only in the progeny of the infected plant. Quanjer (43) has demonstrated this method of spreading by planting diseased and healthy potatoes in pots with and without partitions between the leaves and with and without partitions between the planted tubers. Infection became visible only in the progeny of those plants whose tubers were not separated by a partition. Leaf separation had no effect for if the tubers were not separated the progeny was diseased whether the leaves were separated or not.

CAUSES OF MOSAIC DISEASES.

The causes assigned to mosaic diseases have been as varied as they have been numerous. Beginning with "evil intentions," on the part of some one, numerous causes have gradually been advanced, some with little experimental evidence behind them, only to be discarded, until today we have three general theories advanced. These are, the bacterial, the virus, and the physiological theories. Melchers (III) has summarized these so well that it is unnecessary to go into detail concerning them. That the question of cause is still a disputed one may be gathered from the opposite opinions held by Allard and Freiberg. Allard in 1916 (II) discusses the properties of the virus causing the mosaic disease of tobacco and says the cause is not an enzyme but that there is every reason to believe it to be an ultramicroscopic organism of some kind. Freiberg (II) however says it is an enzyme and not a virus and that the enzyme is not like the oxidases giving the quaiacum reaction, as Woods earlier had laid so much stress on. Allard says because the disease is infectious and capable of increasing in susceptible plants it therefore acts like an organism. Freiberg is not able to account for the initial causes which brought about the formation of this mosaic enzyme but says its production within the diseased plant is in accord with known physiological and pathological principles. Freiberg bases his conclusions upon the reactions which the virus exhibits toward various chemicals and various conditions such as heat and cold, pointing out that they differ little from those exhibited by any chemical compound including enzymes. These reactions will be discussed later.

Quanjer (43) speaking of the rarity with which transmission

of mosaic diseases through the seed takes place says, "it is easy to understand that the embryo is protected from infection," when we consider the causal agent as an ultramicroscopic organism. He says the phloem strands connecting the embryo and the mother plant are interrupted twice and these interruptions protect the embryo from infection. He adds "The embryo feeds by means of osmosis and can only absorb fluid matter. So there is every reason to agree with Allard (1915) that the pathogenic agent is a parasite. That bacteriology has not succeeded in cultivating the organism is no proof that there is no organism present."

Freiberg (II) takes up each point of Allard's work published in 1916 (II) and discusses it, both from the view point of organisms as the cause and also from the view point of enzymes as the cause. Since the time of Freiberg's publication Chapman (13) has summarized and shown us that ultramicroscopic organism, virus and enzyme are all killed or rendered inactive by temperatures below 100°C and that the causal agent in tobacco mosaic sap is thus killed at that temperature. Thus the temperature relations for all three causal agents are practically alike. There are many grounds on which these three causal agents cannot be separated from each other, but Chapman (13) inclines toward the view of some toxin produced by the plant itself as being the cause of the disease. Allard (2) in 1918 tried the effect of various salts, acids, germicides etc., upon the infectivity of the virus causing the mosaic disease of tobacco. He also tried the effect of mixing the virus with soil, kaolin and talc. Beyond giving the effect of these different substances upon the virus he makes no further statement as to the nature of the causal agent.

MEANS OF CONTROL.

Many methods of control have been suggested but usually they have been concerned with prevention rather than treatment, for attacked plants do not recover. Tobacco mosaic control, especially in the past, has been based on liming of the soil and reducingthe intensity of the light. Heavy liming however does not give good results consistently and soon makes the soil alkaline which encourages really serious soil diseases such as Thielavia. Soil sterilization by means of steam or formalin has proved beneficial in controlling the appearance of mosaic of tobacco. The use of new soil for seed beds, lessening of root injury, proper cultivation and drainage, avoiding too much nitrogenous fertilizer and discontinuing the use of "tobacco water," are all suggested as control measures for tobacco mosaic.

In potato mosaic Vogel (61) states, "The establishment and maintainance of the seed plat is the only means of elimination that offers any encouragement at the present time." The Report (48) suggests the selection of the best strains consistent with market requirements as the, "only (method) that can be recommended at present and confidence may be felt that a country-wide adoption of this method will result in a very large increase in yield." With a view to finding the best method of securing fields free from potato mosaic two methods have been tried. One is hill selection, that is, selecting the hills from the appearance of the tops and planting the tubers from the healthy hills. But diseased hills produced diseased progeny and healthy hills produced both healthy and diseased progeny, hence hill selection does not seem

to be a satisfactory means of control, especially in a field where the disease is plentiful. The other method is that of rogueing, that is, the pulling up of diseased plants. In one case a field was given a single rogueing when the plants were 12 inches high and in one year the mottled plants were reduced from 45 to 13 percent. It is suggested that 2 to 3 rogueings by persons acquainted with the disease are better than one, because it gives the aphids less chance to spread the disease. Whether the disease be entirely eliminated by rogueing is not known. Quanjer (43) is doubtful of this point for he says, "The variation in the asexual reproduction is much more limited than in the sexual one; whether it is possible to obtain resistant strains exclusively by selection is doubtful." He suggests that careful attention be paid to mosaic resistance in new varieties obtained by true seed breeding because through asexual reproduction by means of tubers the variation is so small and only through mutations obtained in hybridization, does he think, total immunity can be obtained.

The largest single factor tending toward the elimination of mosaic from potato fields is that of Seed Inspection and Certification. State laws are being enacted, tending toward the inspection of potatoes in the field and after they are dug, and the issuance of a certificate, if they are found to be reasonably free from certain diseases. These laws, all essentially alike, have been put into operation in almost all large potato producing states and have tended to produce seed potatoes much more nearly free from disease. Owing to the prevalence of mosaic when some of these laws were first carried into effect, it was often a question whether to lower the standards and allow heavily mosaic diseased

fields to pass inspection or to reject all fields having over a limited amount of mosaic. Ontario had this difficulty to face but did not lower her standards and through selection and certification have lessened mosaic greatly. To facilitate the raising of disease free seed government seed farms have been established for the production of high grade seed potatoes. Some areas are still free from the disease on potatoes, and in these areas the growers should plant as large areas as possible, isolated from all diseased stock and these areas should be extended until they can supply seed to areas which need it.

McClintock and Smith (32) give us an account of experiments with strains of Savoy spinach in which the seeds were planted and the seeds of the progeny that was not seriously diseased, were saved and planted the next year. These plants were superior in type of plant and resistance to disease to those obtained from regular commercial seed, showing the effect of selection. The results, "point to a possible means of control." Brandes (11) suggests elimination of the sugar cane mosaic by planting immune varieties, though this is perhaps the best means of control only where the disease is very severe and where there is lack of co-operation among all the growers. For the varieties which are immune all have a long growing season and are not wholly desirable for planting in the United States on that account. Breeding experiments to shorten their growing period are being carried on however.

In the Report (49) refering to beans it is stated that, "plants selected for freedom from disease are likely to show mosaic." This also shows the unreliability of hill selection in

eliminating the disease. The Report urges the finding of resistant plants in fields otherwise heavily infected, and also the testing of varieties already found to be resistant, to determine their value for different climates and different soil types. Reddick and Stewart (46)(47) have shown what varieties are immune or resistant and with this, as a basis, the above experimentation can be begun. They say that the development of an immune strain is the best remedy for bean mosaic, though this immune variety will undoubtedly have to be obtained by hybridization of present resistant or immune varieties secured by selection. They think rogueing to be good but probably will not control the disease completely. Cooperative efforts, especially in Michigan are being directed to the raising of disease free seed.

In the case of mosaic diseases for which there are other host plants besides the one economically important, it is of course a control measure to remove these from the vicinity of the crop to be protected. Thus a control measure for sugar cane mosaic is clean cultivation to keep out all grasses known to be susceptible to the disease. Likewise in cucumber mosaic, the wild cucumber serves as a center of infection and should be eradicated from the neighborhood of the crop which it is desired to protect. Very closely connected with this, because of their importance in transmission, is the matter of insect control. "Insect control is imperative," as Melchers (34) says, but the difficulty of insect control is well known. Fumigation is the rather simple solution of the problem in the green house, but out of doors this is impracticable. Sanitation should be practised, because the part played by old infectious matter is not yet thoroughly known.

Workmen should be very careful in all operations, especially the "topping" of tobacco and its transplantation from the seed beds to the field, in order to avoid injury and unnecessary handling. Allard (1) has shown that thorough washing several times with soap and water will remove the infective principle from the hands of the workmen. This is a method which sould be used at intervals when handling the diseased and healthy seedlings in transplanting. Care should likewise be exercised in the cultivation of the plants to avoid unnecessary injury to the roots or tops.

In the case of bean mosaic, which is transmissable through the seed, Reddick and Stewart (47) tried various methods of seed treatment, such as dry and moist heat and various disinfectants, but in every case where the seed retained its viability the virus did also. Experiments to determine the vitality of the virus after a period of storage of the seed would be suggestive.

CLOVER MOSAIC.

Clover mosaic has been mentioned in literature but once to the writers knowledge. This was by Rosen (52) in his recent bulletin from the Arkansas station on the mosaic disease of sweet potatoes. He says; "In addition, Dr. J. A. Elliot has had under observation a peculiar mottling of various clovers including Melilotus alba, Trifolium pratense and T. repens." So we know little about the distribution of clover mosaic. The writer in October, 1919, examined yard square quadrats from two red clover fields near Mission Fields, Illinois with the results given below.

QUADRAT I.

In red clover field south of interurban car tracks, upland, fairly heavy stand of red clover, second crop, some of it in bloom and in seed. Total number of clover plants in quadrat, 49, distributed as follows:

	NO MOSAIC	LIGHT MOSAIC	MEDIUM MOSAIC	HEAVY MOSAIC
NO. OF PLANTS	9	10	13	17
PER CENT	18	20	27	35

PERCENT NOT AFFECTED	18
PERCENT AFFECTED	82

QUADRAT 2

In red clover field north of interurban car tracks, upland, yound stand of clover, planted to clover with a nurse crop that spring, plants small and numerous. Total number of clover plants in quadrat, 86, distributed as follows:

	NO MOSAIC	LIGHT MOSAIC	MEDIUM MOSAIC	HEAVY MOSAIC.
NO. OF PLANTS	44	27	15	0
PERCENT	51	31	17	0

Percent not affected 51

Percent affected 48

Later in October, 1919 three quadrats from the same field in which Quadrat 1 was located, were examined with the following results:

Quadrat 3

Total number of clover plants in quadrat, 122, distributed as follows:

	NO MOSAIC	LIGHT MOSAIC	HEAVY MOSAIC
NO. OF PLANTS	38	46	38
PERCENT	31.1	37.7	31.1

Percent not affected 68.8

Percent affected 31.1

QUADRAT 4

Total umber of clover plants in quadrat, 101, distributed as follows:

	NO MOSAIC	LIGHT MOSAIC	HEAVY MOSAIC
NO. OF PLANTS	43	26	32
PERCENT	42.6	25.7	31.6

Percent not affected 57.3

Percent affected 42.6

QUADRAT 5

Total number of clover plants in quadrat, 49, distributed as follows:

	NO MOSAIC	LIGHT MOSAIC	HEAVY MOSAIC
NO. OF PLANTS	9	14	26
PERCENT	18.3	28.5	53.0

Percent not affected 81.5

Percent affected 18.3

AVERAGE OF QUADRATS 3, 4, AND 5.

	NO MOSAIC	LIGHT MOSAIC	HEAVY MOSAIC	PERCENT AFFECTED	PERCENT NOT AFFECTED.
NO. OF PLANTS	30	29	32		
PERCENT	31	30	39	70	30

Average number of clover plants per quadrat 90.

From these results we see that the amount of infection varied from 48 to 82 percent. The field of young red clover showing only 48 percent infection, while the average of the field with an old stand of clover was 76 percent of the plants infected. The owner of the field in which QUADRATS 3, 4 and 5 were located said the field had suffered severely from an attack of locusts during the summer. It is quite possible the locust acted as an agent of dissemination of the disease and consequently caused a high percent of diseased plants. On the other hand the field in which QUADRAT 2 was located, the clover was protected by the nurse crop from the ravages of the locust. Mosaic was observable in practically all fields of red clover around Urbana and Champaign with an infection of probably 25 percent though only a small portion of this 25 percent was severely mosaic diseased.

The loss due to clover mosaic is probably negligible, unless it increases in severity as some other recently discovered mosaic diseases have. The habit of forming low clumps, most of which

escape the mower, would give a lessened yield, as would the decrease in size of leaflets. But the value of any study of clover mosaic lies in the light it may throw on other really important mosaic diseases.

It has often been stated that mosaic diseased plants are more subject to other diseases than are normal plants. While working over the leaves of mosaic diseased and healthy clover, the apparently greater abundance of rust on the diseased leaves than on the healthy, was noticed, and counts were made to ascertain the correctness of this assumption. The amount of rust expressed in percent on the heavy mosaic and the no mosaic leaves are as follows:

Kind of Mosaic	Light Rust	Medium Rust	Heavy Rust
Heavy Mosaic	45.7	41.0	13.3
No Mosaic	62.1	27.6	103

or a slightly greater amount of rust on the heavily mosaic diseased leaves.

The mosaic disease of clover is characterized by a distinct mottling of the leaflets. This mottling varies in intensity depending on the severity of the disease. The pattern of the mosaic varies with the severity likewise. A leaf mildly mosaic diseased, has only a few light yellowish areas of varying shape on the leaflet while in a more severe case the ground color of the leaflet may be yellowish with a few scattered islands of dark green. The light colored areas usually, especially in a mild case of mottling, follow the spaces between veins but later may disregard the veins as boundries and finally make the whole leaflet surface yellowish.

The light spots become lighter and the dark green spots become a darker green as the disease becomes more severe. The leaf surface is somewhat wrinkled and the edges slightly crimped. (fig. 4). Rarely the leaflets are somewhat dwarfed and narrowed. (fig. 5). The habit of the severely diseased plant is always a little more dwarfed and bushy than is the normal. This is quite evident when studying the disease in the field. In the field all the leaves of one plant were uniformly patterned, that is, the porportion of light and dark areas was the same on all leaves. This was not always true, however, indicating that the plant may have become infected late in the season and only the new, more rapidly growing leaves, showed symptoms. This was the case with green-house plants which became infected artificially or apparently through insect transmission. In these the leaves which were produced after the inoculation were more severely infected than the others. In the field some plants were very bushy with large crowns and many branches but none of the branches grew up more than a few inches high as compared with the normal plants, which sent up leaf and usually flower bearing stalks 10 or more inches high. These bushy plants were always severely diseased and nearly all the leaves were uniformly patterned indicating the plant had been diseased for some time. Healthy and diseased plants intertwined closely and the leaves of the healthy plant would come up in the midst of the diseased bush but if one traced this down it would always be found to belong to a healthy crown. This description so far refers to red clover; mammoth clover proved to have the same symptoms. On white clover however, no disease was found. On some plants in the green-house where insect transmission may have infected the plants,

there were a few leaflets with lighter areas but these always seemed to distort the leaf only at that one place and not give a general wrinkled appearance all over the leaf, also there was no mottling resembling the mottling on red clover leaves. Alsike clover showed mild cases of mosaic on some of the younger leaves.

Sections through diseased leaves show the yellowed areas as distinctly thinner and with a light colored appearance showing the lessened number or almost total absence of chloroplasts. The palisade cells, likewise, are shortened until they are almost isodiametric and this causes the greater thinness of the leaf. The darkgreen areas appear normal with the chloroplasts plentiful. Beyond this, very few changes are observable.

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Raymond Kienholz.

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TABLE I. LOSSES DUE TO MOSAIC.

STATE	POTATO MOSAIC		BEAN MOSAIC	
	Percent decrease	Decrease in bushels,000 omitted	Percent decrease	Decrease in bushels,000 omitted
Maine	10.	2,489	-	-
New Hampshire	15.	519	-	-
Vermont	15.	596	t	+
Massachusetts	8.	416	2.	+
Rhode Island	2.	13	-	-
Connecticut	1.	25	t	+
New York	4.5	1,647	15.	293
New Jersey	10.	940	8.	2
Pennsylvania	5.	1,284	15.	10
Delaware	t.	+	-	-
Maryland	t.	+	t	+
Virginia	t.	+	t	+
W. Virginia	t.	+	t	+
N. Carolina	.5	21	-	-
S. Carolina	1.	29	-	-
Georgia	1.	16	e	e
Florida	2.	71	-	-
Ohio	1.	112	-	-
Indiana	t.	+	+	+
Illinois	t.	+	-	-
Michigan	1.	288	2.	100
Wisconsin	t.	+	t	+
Minnesota	t.	+	-	-

STATE	POTATO MOSAIC		BEAN MOSAIC	
	Percent decrease	Decrease in bushels,000 omitted	Percent decrease	Decrease in bushels,000 omitted
Iowa	t.	+	-	-
Missouri	t.	+	-	-
N. Dakota	t.	+	-	-
S. Dakota	t.	+	t	+
Nebraska	t.	+	e	e
Kansas	t.	+	1.	+
Kentucky	t.	+	t	+
Tennessee	2.	71.	5.	5
Alabama	15.	847	t	+
Mississippi	12.	218	-	-
Louisiana	15.	767	3.	+
Texas	7.	248	2.	+
Oklahoma	2.	26	-	-
Arkansas	4.	100	4.	+
Montana	t.	+	-.	-
Wyoming	-	-	-	-
Colorado	t.	+	-	-
N. Mexico	-	-	e	e
Arizona	-	-	e	e
Utah	-	-	-	-
Nevada	-	-	-	-
Idaho	-	-	t	+
Washington	t.	+	t	+
Oregon	t.	+	20.	23
California	2.	263	t	+

	POTATO MOSAIC		BEAN MOSAIC	
STATE	Percent decrease	Decrease in bushels,000 omitted	Percent decrease	Decrease in bushels,000 omitted
United States	2.3	11,006+	1.78	433.+

Production of Bushels in 1918, 400,106,000.

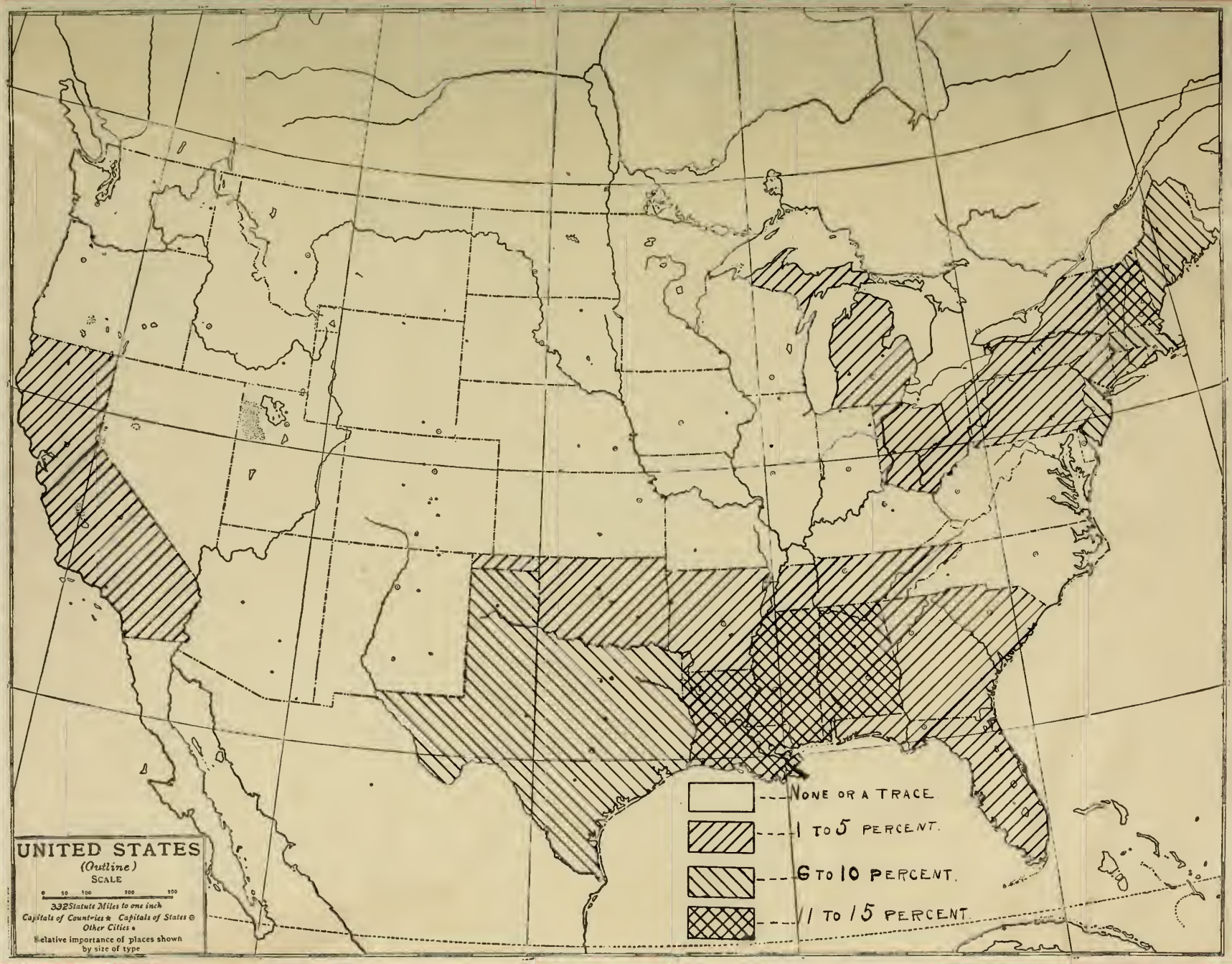
t = trace

- = no report

e = none present

+ = too small to be estimated

Figure 1.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Relative importance of places shown by size of type

Figure 2. Distribution and prevalence of POTATO MOSAIC

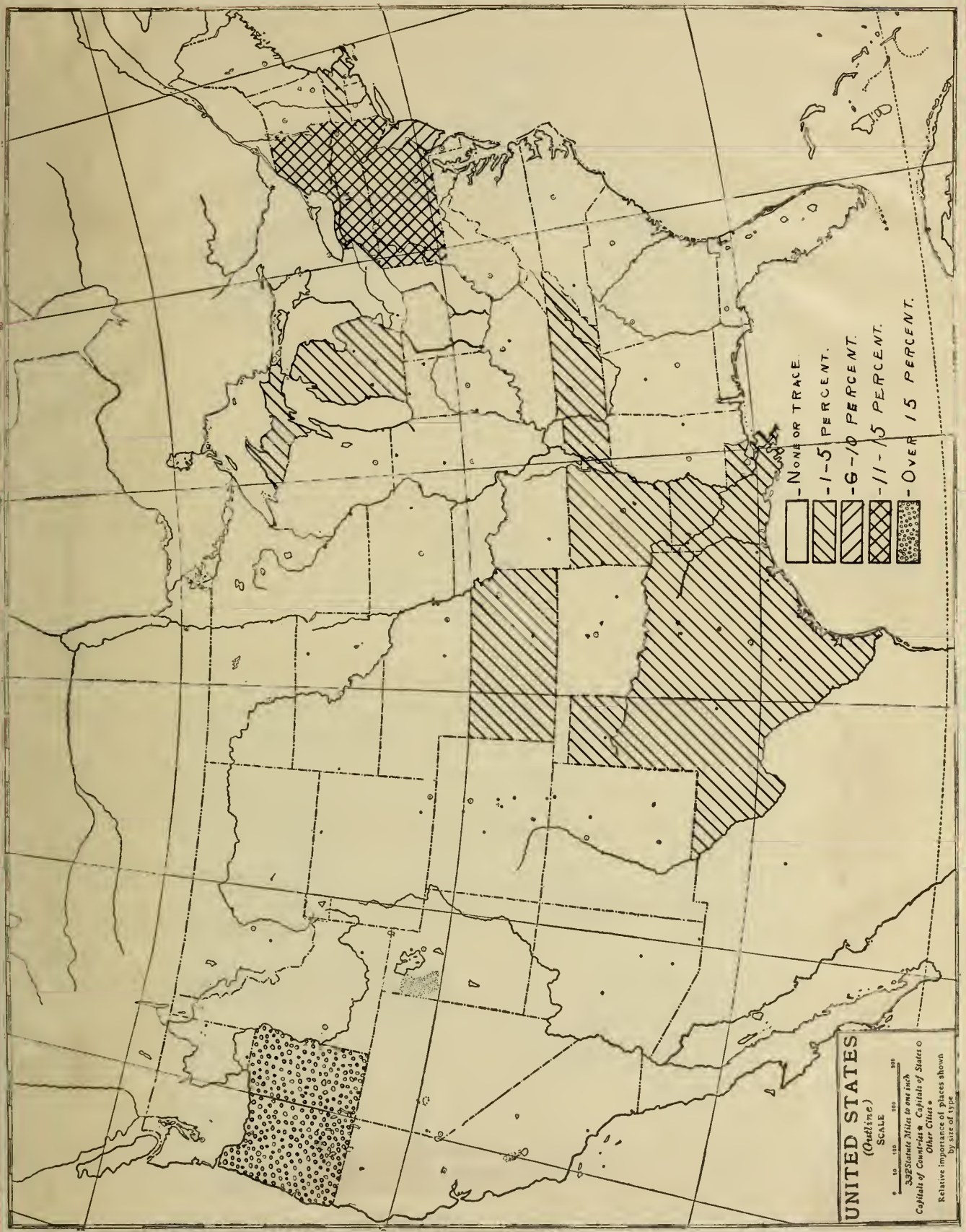

Figure 3. Distribution and prevalence of BEAN MOSAIC

Figure 4.

Figure 5.

Figure 6.

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